

# Testing of a photon-counting optical ground receiver with emulated space-to-ground link effects

SPIE Photonics West, Free-Space Laser Communications XXXVI

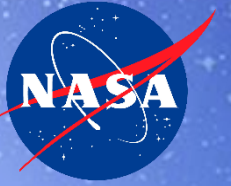
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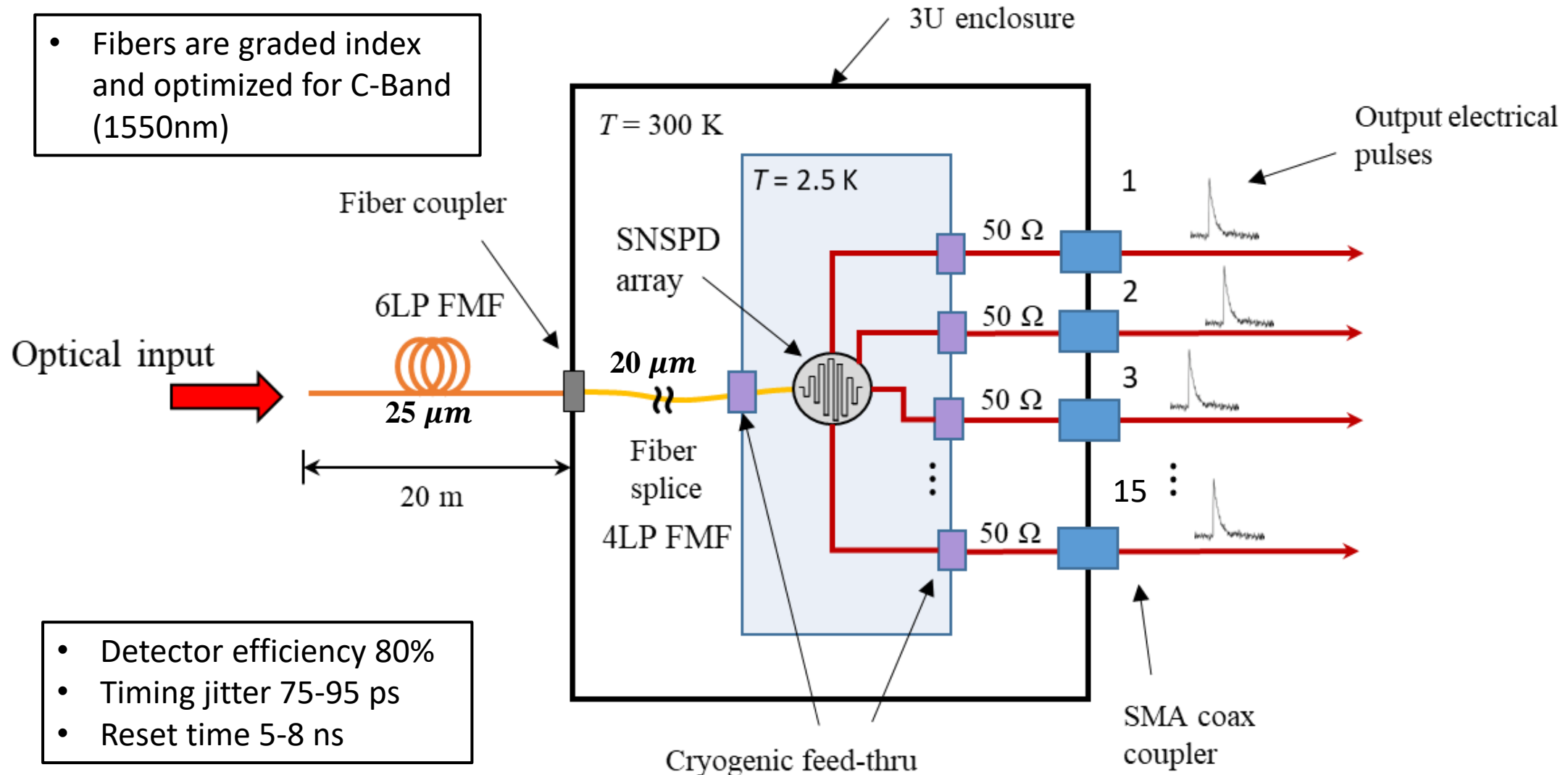


# Introduction

- NASA Glenn Research Center is creating a COTS based real-time optical receiver compliant with the Consultative Committee for Space Data Systems (CCSDS) Optical Communications High Photon Efficiency (HPE) standard.
- Current implementation status:
  - PPM orders of 16, 32
  - Code rates of  $1/3$ ,  $1/2$ , and  $2/3$
  - Slot widths of 0.5, 1, 2 ns
- Goals:
  - Demonstrate with NASA Goddard's Low-Cost Optical Terminal (LCOT) for Optical Artemis-2 Orion (O2O) demonstration.
  - Publish COTS based receiver system architecture and finished code to NASA's Software Repository for Industry use.

# Fiber Interconnect and Detectors

- Fibers are graded index and optimized for C-Band (1550nm)



- Detector efficiency 80%
- Timing jitter 75-95 ps
- Reset time 5-8 ns

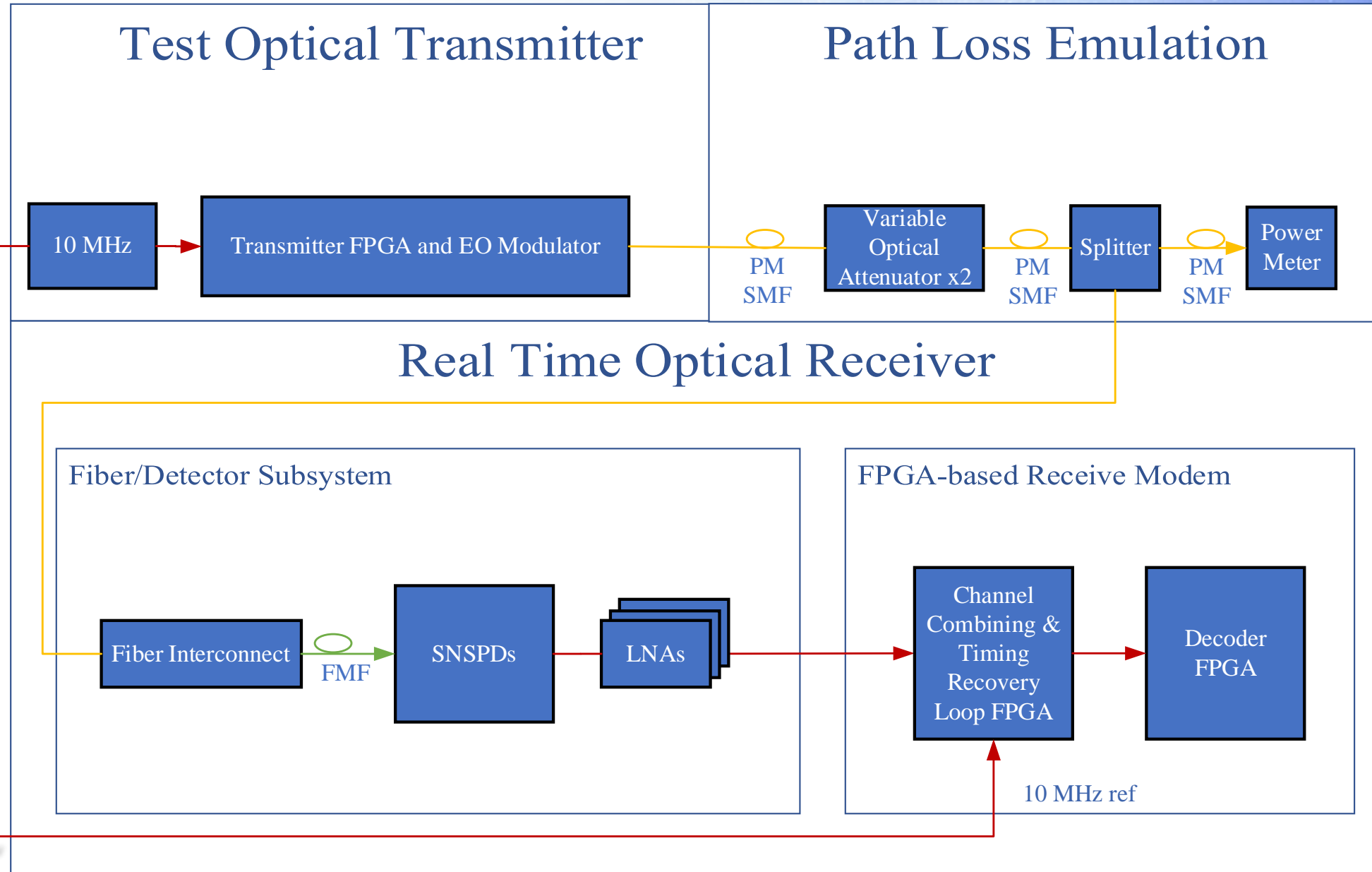
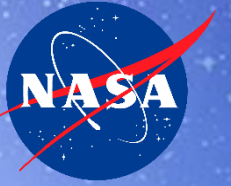
# FPGA-based Receiver Modem



- 2 FPGAs housed in a MicroTCA chassis.
- Timing Recovery FPGA is a Xilinx Zynq UltraScale+ Radio Frequency System-on-Chip (RFSoc) with 16 ADCs
- Decoding FPGA is a Xilinx Virtex UltraScale with embedded PowerPC processor



# Test Setup

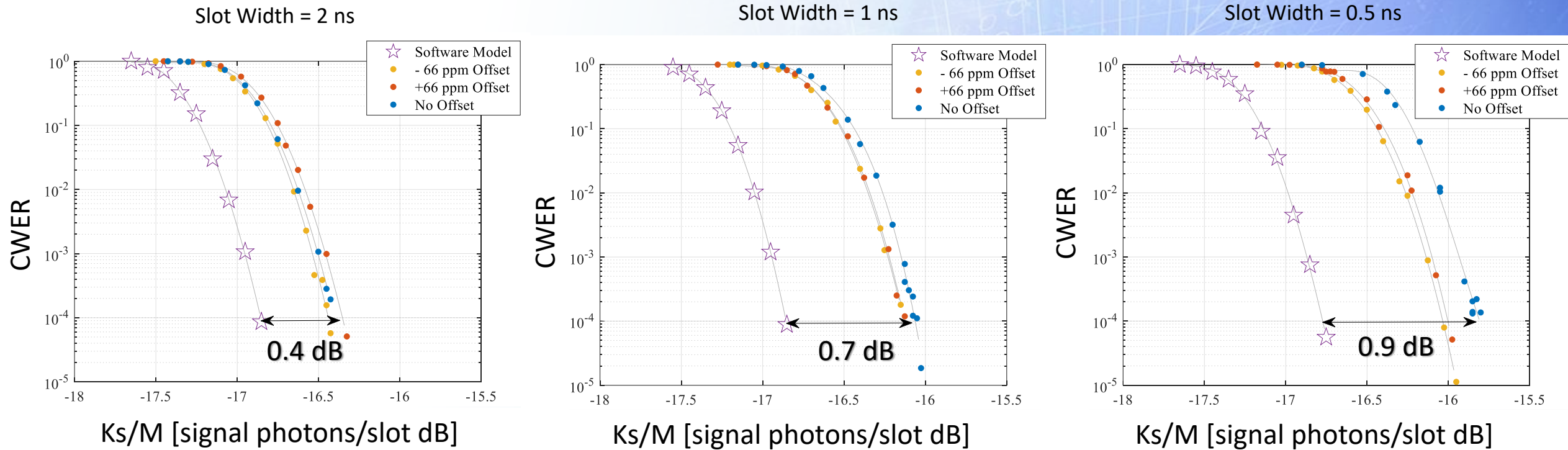
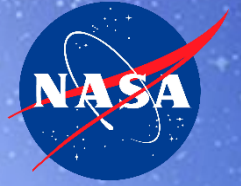


# Tests Performed



- SCPPM Test Mode
  - PPM-32, code rate 1/3
  - Pulse slot widths of 2 ns, 1 ns and 0.5 ns
  - Convolutional channel interleaver of size N=84 (rows) and B=4140 (row length parameter)
- Codeword error rate (CWER) with clock offsets ( $\pm 66$ ppm)
  - Doppler shifts  $\pm 9$  GHz, ( $\pm 46$  ppm)
  - Transmitter clock accuracy ( $\pm 20$  ppm)
- Dynamic Range
  - Detector delay effects
  - Upper and lower limitations

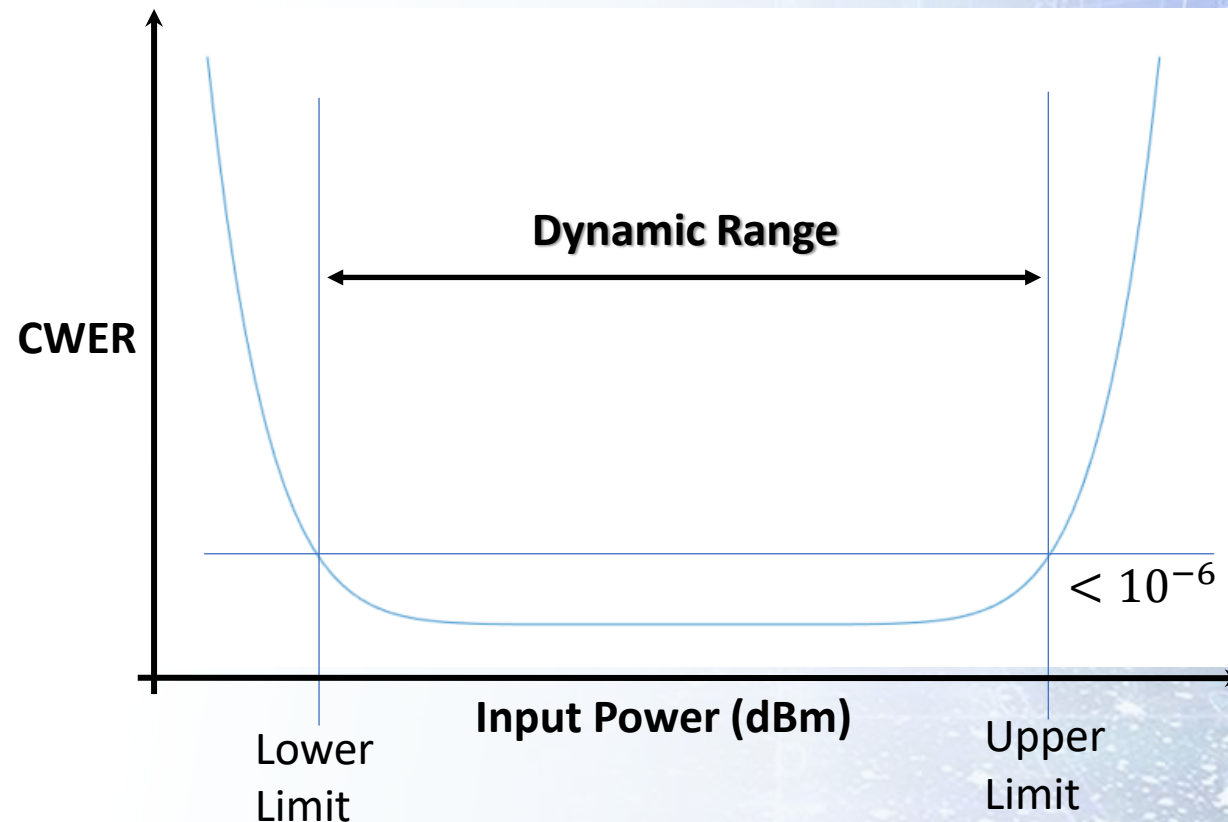
# Codeword error rate (CWER) with Doppler shift and transmitter clock error



- ✓ Less than a 0.2 dB difference between the CWER curves with and without Doppler
- ✓ FPGA implementation and Detector Jitter loss range from 0.4 dB to 0.9 dB

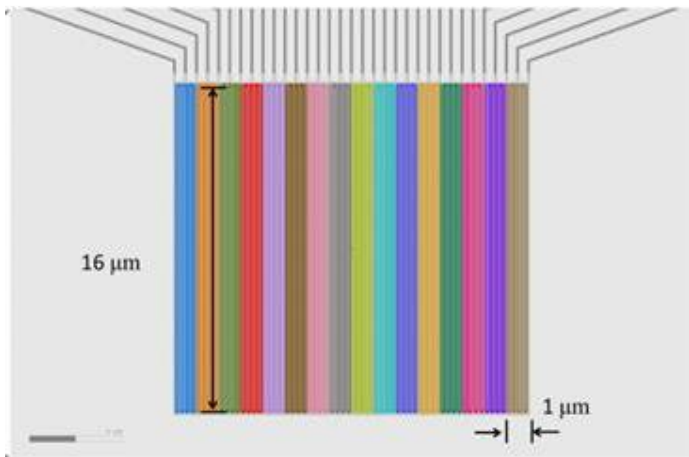
# Dynamic Range

- Dynamic range: Ratio between the upper and lower input power limits of the receiver system

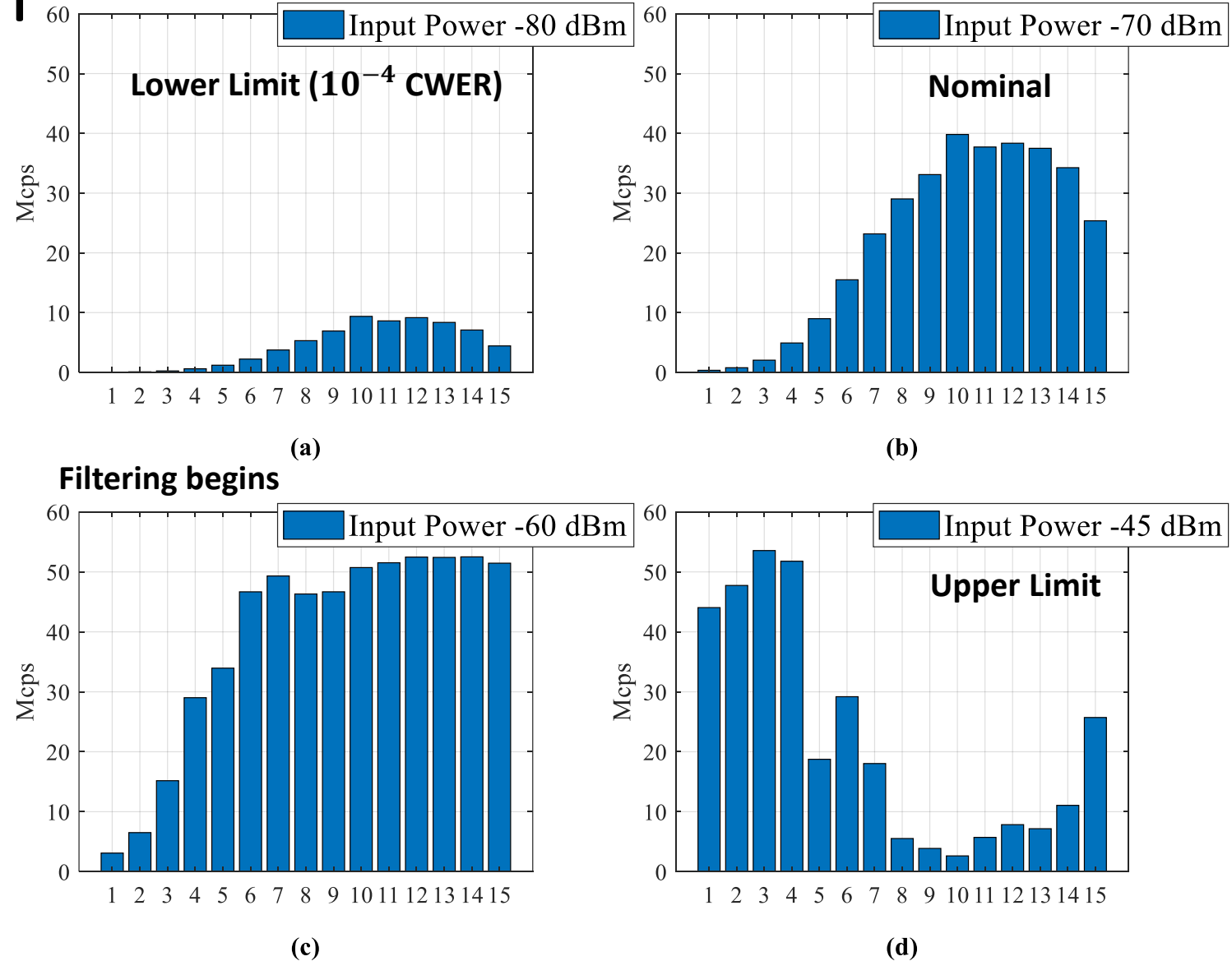


# Channel Distribution

- Center channels receive more power and reach saturation at a lower input power level than edges of the array
- Channels with >50 Mcps are filtered out, due to becoming mis-aligned.

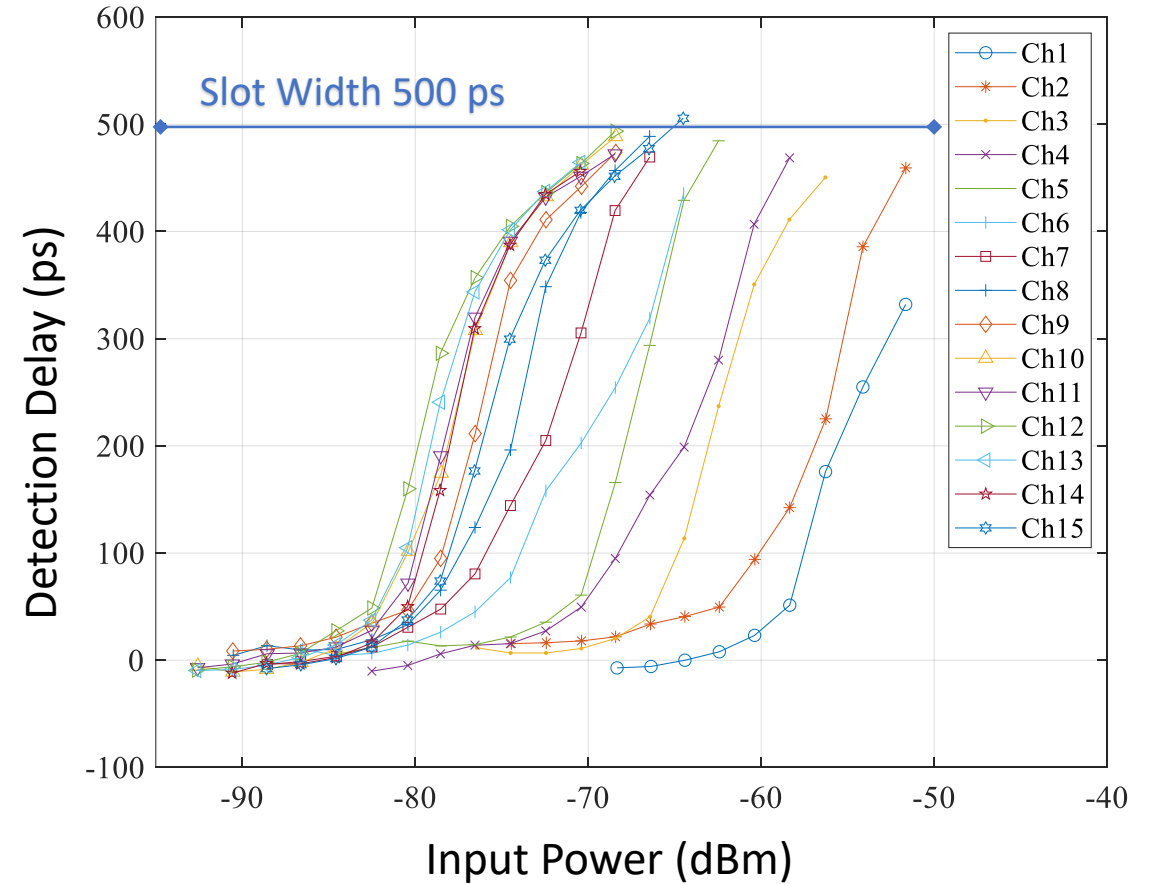
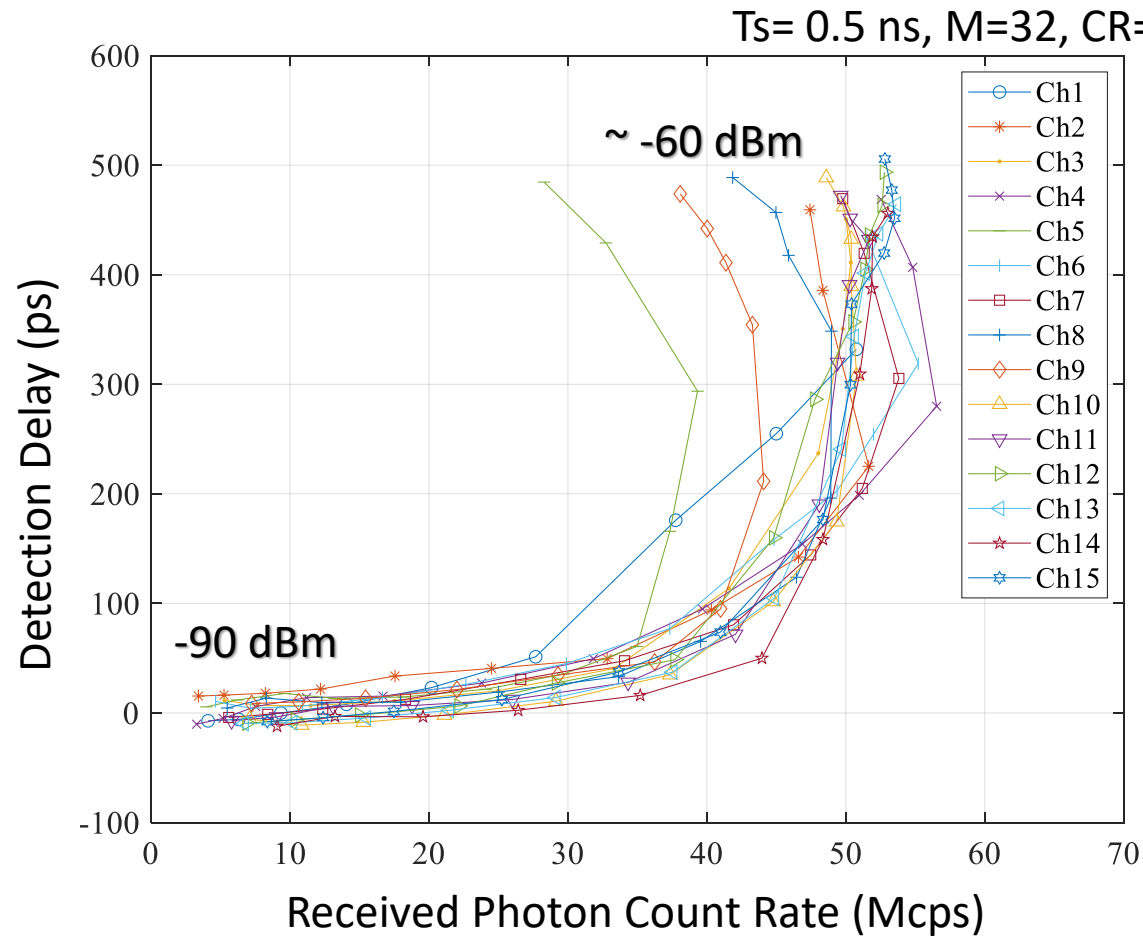
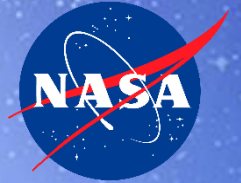


$T_s = 0.5$  ns,  $M=32$ ,  $CR=1/3$  and Data rate=83 Mbps

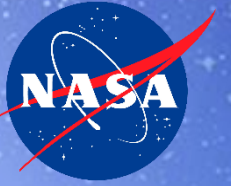


Detector Counts Distribution: (a) Input power -80 dBm; (b) Input power -70 dBm; (c) Input power -60 dBm; (d) Input power -45 dBm.

# Detection Delay



- This photon flux dependent detection delay is a problem when each detector receives a different input photon flux and become mis-aligned at high photon flux.

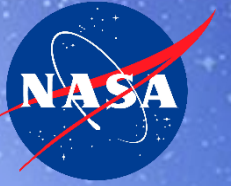


# Dynamic Range – Results

- Lower limit: limited by the performance of forward error-correction code
- Upper limit: limited by detection delay changing at higher photon flux rates

**M=32 and CR=1/3**

Ts (ns)	Data Rate (Mbps)	Dynamic Range (dB)
2	21	33
1	42	28
0.5	83	37



# Conclusion

- A photon-counting COTS based receiver system was characterized and tested with emulated space-to-ground communication link effects.
  - CCSDS HPE SCPPM waveform with PPM-32 and code rate 1/3, with slot widths of 2 ns, 1 ns, and 0.5 ns, with convolutional channel interleaver of size  $N=84$  and  $B=4140$ .
- FPGA implementation and detector jitter losses ranged from 0.4 dB to 0.9 dB
- Doppler shift and space transmitter clock differences with  $\pm 66$  ppm clock differences show minimal performance impact ( $< 0.2$  dB).
- Receiver dynamic range ( $> 28$  dB) is limited by changing SNSPD detection delays at high photon flux rates.



# Acknowledgements

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[www.nasa.gov/SCaN](http://www.nasa.gov/SCaN)